

THE EFFECT ON OPERATIONAL AND TACTICAL SURPRISE
BY U.S. MILITARY FORCES DUE TO THE PROLIFERATION
OF UNCLASSIFIED SATELLITE IMAGING SYSTEMS

A thesis presented to the Faculty of the U.S. Army
Command and General Staff College in partial
fulfillment of the requirements for the
degree

MASTER OF MILITARY ART AND SCIENCE

by

EDWIN C. SWEDBERG, MAJ, USAF
B.S., University of Texas, Austin, Texas, 1982
M.S., Northrop University, Los Angeles, California, 1987

Fort Leavenworth, Kansas
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Thesis Title: The Effect on Operational and Tactical Surprise By U.S.
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Imaging Systems

Approved by:

Benjamin Tyler, Jr., Thesis Committee Chairman
LTC Benjamin Tyler, Jr., M.A.

Robert R. Soucy II, Member
LTC Robert R. Soucy II, M.S.

Daniel F. Moorer, Jr., Member
MAJ Daniel F. Moorer, Jr., M.S.

Kenneth R. Garren, Member, Consulting Faculty
COL Kenneth R. Garren, Ph.D.

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Philip J. Brookes, Director, Graduate Degree Programs
Philip J. Brookes, Ph.D.

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ABSTRACT

THE EFFECT ON OPERATIONAL AND TACTICAL SURPRISE BY U.S. MILITARY FORCES
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TABLE OF CONTENTS

	<u>Page</u>
APPROVAL PAGE	ii
ABSTRACT	iii
LIST OF ILLUSTRATION	v
LIST OF TABLES	v
CHAPTER	
1. INTRODUCTION	1
2. REVIEW	18
3. RESEARCH METHODOLOGY	39
4. ANALYSIS	48
5. CONCLUSIONS AND RECOMMENDATIONS	78
BIBLIOGRAPHY	83
INITIAL DISTRIBUTION LIST	87

LIST OF ILLUSTRATION

Figure	<u>Page</u>
1. U.S. Capitol, Washington, D.C.	28

LIST OF TABLES

Table	<u>Page</u>
1. Specifications for Three Proposed Commercial Remote Sensing Systems.	26
2. Example of Potential Criterion Matrix Used to Support Measurement Research Phase	44
3. Summary of Key Satellite Parameters	62
4. Detection of Target Observables	64
5. Criteria Ranks and Thresholds	68
6. Weighted Decision Matrix	69
7. Selected Satellite Systems and Parameters	70

CHAPTER 1

INTRODUCTION

The topic of this thesis is the effect of the proliferation of unclassified satellite imaging systems on US military operational and tactical surprise. This proliferation by satellite imaging system developers and satellite imagery users in the fields of media, science, and commercial enterprise severely jeopardizes the ability of the US to achieve military surprise.

This chapter covers a brief synopsis of remote sensing terminology, history, and applications; the importance of surprise in warfare; and potential countermeasures to satellite imaging systems. It concludes with the thesis questions and a brief discussion of assumptions, limitations, and delimitations.

In recent history, the United States has enjoyed a technological and organizational superiority in the area of intelligence collection. The US has had the capability to gather a wealth of information at all levels of warfare on enemy intentions, force posture and composition, and weapon system capabilities. On the other hand, most actual and potential adversaries (the Soviet Union/Russia excluded) have not had the capability to gather similar intelligence information on US forces. The US has normally been in a position to deny the gathering of information by an enemy using the collection assets within his means (e.g., ground reconnaissance units, aircraft reconnaissance).

This situation will change if all that an adversary has to do is order a very recent remote sensing product of his area-of-interest for environmental or commercial purposes. An adversary could even more easily turn on the Cable News Network (CNN) and see a near real-time satellite image of the battlefield.

Remote Sensing Terminology

What is remote sensing? A definition is given by Torleiv Orhaug of the National Defence Research Institute in Linkoping, Sweden:

Observation satellites are used to register objects and activities on, below, or above the surface of the earth. For several reasons, including the distance involved, the most effective means of obtaining such information is by the use of electromagnetic radiation. This may involve the following mechanisms: (a) the scattering/reflection from the scene (objects and background) of incoming natural electromagnetic radiation (light and microwaves); (b) the scattering reflection of man-made radiation (radar systems, laser systems, and so on); (c) the generation of natural electromagnetic radiation due to the physical temperature of objects (so-called Planck radiation). . . .

In civilian applications, the use of the . . . above methods is often labelled [sic] remote sensing (using passive or active sensors). ¹

In other words, remote sensing (also referred to as satellite imaging) is the space-based detection of either the reflected energy from the sun or a man-made source (i.e., radar emitter co-located on the imaging satellite) or the emitted energy from a thermally radiating object. The three types of remote sensing systems, corresponding to the above three cases, are commonly referred to as electro-optic, synthetic aperture radar, and thermal infrared imaging systems, respectively.

All modern remote sensing systems use digital imaging technology. In digital imaging, reflected or emitted electromagnetic

energy impacts the satellite's focal plane and is converted into digital information. This digital information is then transmitted to a ground station where it is processed and converted back into an image for man or machine use.

Several critical parameters used to characterize the quality of remotely sensed digital imagery data are spatial resolution, spectral resolution, area coverage, and revisit time. Each of these contributes to the information value contained within the imagery products from a remote sensing system. It should be noted that none of these parameters are exclusive of each other. Improving one parameter typically results in another parameter being degraded. The process of optimizing a satellite imaging system for specific applications is a science of trade-offs.

Spatial Resolution

The first critical parameter, spatial resolution, refers to the smallest-sized object that can be detected on the earth's surface. It can be defined as "the area on the ground that a single pixel (a light-sensitive picture element) sees at any given instant."² The smaller (or finer or higher) spatial resolutions allow the interpreter to discern smaller sized targets. Conversely, a larger (or coarser or lower) spatial resolution can only yield information on larger targets.

Spectral Resolution

Spectral resolution, the second critical parameter, refers to "the portions or [spectral] bands which can be recorded by [a remote sensing] instrument."³ Objects on the earth reflect and emit

electromagnetic energy. Due to characteristics, such as material composition, surface texture, and angle of incidence, this energy varies by object. It is called the object's spectral signature. Different remote sensing instruments detect different parts of the electromagnetic spectrum and can, therefore, characterize different objects.⁴ A remote sensing instrument can either be single band or multispectral. A single-band instrument focuses within a single discrete area of the spectrum (i.e., a panchromatic sensor which images the broad band of visible light in various shades of gray). A multispectral instrument focuses simultaneously within multiple bands of the spectrum (i.e., imaging the blue, green, and red visible bands discretely and combining them to form a color image).

Area Coverage

Area coverage is the third critical parameter of digital remote sensing systems. Area coverage is the amount of area on the ground that can be imaged during a single imaging operation window. Typically, it is a function of swath width and other optical, electronic, and data handling characteristics of the imaging sensor. Because of the inverse relationship between spatial resolution and communications data rate, the higher the spatial resolution the more communications bandwidth needed to send the image from space to the ground. There is also typically an inverse relationship between spatial resolution and area coverage. To image a large area of the earth's surface with a high spatial resolution digital instrument would take an incredible amount of

down-link capacity.⁵ This data-rate limitation is why most commercial large area coverage systems have had very coarse spatial resolution.

Revisit Timeliness

The final critical parameter which impacts on the quality of remote sensing data is revisit timeliness. Revisit is the ability of a satellite to cyclically image the same point or area on the ground and is dependent on the satellite's orbital and instrument pointing characteristics. This cycle length varies from daily to every 44 days depending on the orbital characteristics of the satellite system.⁶ Obviously, the quicker a satellite can re-image the same area, the greater its military utility.

Remote Sensing History

Civilian remote sensing of the earth from space began with the launch of the TIROS-1 satellite in 1970 by the US National Oceanic and Atmospheric Administration (NOAA). This weather satellite provided repetitive global coverage but with very coarse spatial resolution. The current heir to TIROS-1 is the NOAA-12 weather satellite launched in May 1991. Its sensor suite includes the Advanced Very High Resolution Radiometer (AVHRR) instrument which provides coarse one-kilometer spatial resolution over a large area.⁷

Remote sensing data with better spatial resolution has been available since the launch of the first LANDSAT satellite by the United States in 1972. The early LANDSAT satellites (vehicles 1-3) provided global coverage of the earth with the Multispectral Scanner (MSS). The MSS provided imagery in four spectral bands (green, red, and two near-

infrared) at an 80-meter spatial resolution. The MSS swath width was 185 kilometers and its revisit time was 18 days.⁸

Follow-on LANDSAT satellites (vehicles 4-5) added a second instrument, the Thematic Mapper (TM), when LANDSAT 4 was launched in 1984. The TMs spatial resolution increased to 30 meters for its six reflective bands (blue, green, red, near-infrared, and two short wave-infrared) and 120 meters for its one thermal-infrared band. The TM swath width remained at 185 kilometers, and its revisit time improved to 16 days.⁹

International competition in earth remote sensing began in 1985 with the launch by the French of the first SPOT imaging satellite. Each of the three SPOT satellites launched to date image in four discrete spectral bands: a single panchromatic band which provides 10-meter spatial resolution and fore-and-aft-looking stereo (used to extract surface elevation data) and three 20-meter multispectral bands in the green, red, and near-infrared portions of the spectrum. SPOT can image a swath width of 60 kilometers within an access area 950 kilometers wide (possible because of a steerable mirror). Due to this steerable mirror, its revisit time varies from 3 to 26 days depending on latitude.¹⁰

Several other countries and groups of countries have joined the commercial remote sensing community. In 1987, both India and Japan launched their first imaging satellites. The Indian system, IRS-1, has a spatial resolution in the 36-to-72-meter range, with four spectral bands, and a 22-day revisit time. The Japanese system, JERS-1, has a 50-meter spatial resolution, four spectral bands, and a 17-day revisit cycle. In 1989 the European Space Agency launched the first ERS-1

imaging satellite with 25 to 30-meter spatial resolution, a single band, and a three-day revisit time.¹¹ The Russians have also joined the commercial market, selling high quality images through its own distribution agency, Soyuzkarta.¹²

The future of remote sensing from space points to ever increasing capability. As the data derived from commercial imaging systems is perceived as more valuable and as the cost of putting improved systems into orbit drops, more countries and more corporations will become involved. Already, several extremely capable systems reside somewhere between the drawing board and testing within the thermal-vacuum chamber. In later chapters, this thesis examines several of these satellite imaging systems in the context of their utility for detecting military operations.

Remote Sensing Applications

Since the launch of the first LANDSAT remote sensing satellite, the use of unclassified imagery from space has grown to support a large and diverse group of applications. Scientists have been using satellite multispectral imagery to assess changes to the environment over time. Entrepreneurs have used this imagery for mineral exploration and crop yield assessment. Government agencies have used it for forest, rangeland, and wetland management; for oceanographic analysis; and for demographic monitoring. The media has just recently begun to tap its potential for current event monitoring and area orientation. According to Aviation Week & Space Technology in 1987:

The news media has stepped up its use of Landsat [sic] and Spot [sic] scenes since the start of commercial remote-sensing

marketing. The OTA [Congressional Office of Technology Assessment] report cited the Chernobyl nuclear accident, the Soviet shuttle site at Tyuratam and the Iran/Iraq war as three instances in which satellite photography was used extensively to cover news events.¹³

Earth remote sensing is a growth field and its technology is expanding to satisfy the marketplace.

As more capable systems were placed in orbit during the 1980s, military and intelligence organizations began to realize a potential to use these civilian imaging systems to augment classified systems. These systems were of adequate quality to provide imagery over large areas to support applications such as trafficability assessment, terrain analysis, mapping, amphibious assault planning, and target analysis.¹⁴

As the next generation of civil and commercial satellite imaging systems are launched over the next decade, many governments will realize that they can use them as a primary source of operational military intelligence. Indeed, some have already demonstrated this interest. According to Thomas G. Mahnken, an analyst with SRS Technologies, "Iraq relied extensively upon satellite imagery during its war with Iran, and, soon after the invasion of Kuwait, representatives of the Iraqi government tried to purchase current imagery of the Middle East."¹⁵ Future satellite imaging systems will provide increased accessibility, higher quality, and more timely delivery of products than has ever been available in the past. These systems could provide future adversaries with the means to monitor US preparation for military operations and thus prepare a counteracting course of action.

Surprise in Warfare

Surprise is viewed by all of the US military services as a critical element in warfare. Both the US Army and US Air Force refer to surprise as one of the Principles of War in their keystone doctrinal manuals, FM 100-5, Operations, and AF Manual 1-1, Basic Aerospace Doctrine of the United States Air Force, respectively. Both of these manuals define surprise as the ability to "strike the enemy at a time or place or in a manner for which he is unprepared."¹⁶ In other words, the enemy may know of an impending attack, but has no time to react. The US Marine Corps in its key war fighting manual, FMFM 1, Warfighting, gives the same definition shown above and refers to surprise as a "genuine multiplier of strength" and states that "the desire for surprise is 'more or less basic to all operations, for without it superiority at the decisive point is hardly conceivable.'"¹⁷ In FM 100-5, the Army goes further than the Air Force or Marines with its emphasis on surprise. The Army includes it as one of the characteristics of offensive operations and a key component of initiative. Army doctrine states that "knowing the enemy commander's intent and denying his ability to conduct thorough and timely intelligence is crucial."¹⁸ Joint doctrine also stresses the element of surprise. Joint Pub 1 states that "maintaining freedom of action is vitally important" and one component of this is "gaining the fullest possible surprise."¹⁹ Given the United States military's emphasis on surprise, any adversary's capability to counter that element of surprise could be severely damaging.

Countermeasures

If the current trend in commercial remote sensing is to place into orbit more and more imaging systems with the ability to detect military operations and if the detection of these military operations by a potential adversary places the element of surprise at risk, is there anything that can be done to counteract this detection? Three broad approaches covered include domestic policy, foreign diplomacy, and active and passive countermeasures.

Policy can be enacted by the US government to prevent the release of data from US-controlled satellite systems to adversaries in time of crisis. The Presidential Decision Directive (PDD) signed on 9 March 1994 outlines such a policy. The policy lists conditions for US firms to receive a license to operate private remote sensing space systems and states that:

During periods when national security or international obligations and/or foreign policies may be compromised, as defined by the Secretary of Defense or the Secretary of State, respectively, the Secretary of Commerce may, after consultation with the appropriate agency(ies), require the licensee to limit data collection and/or distribution by the system to the extent necessitated by the given situation.²⁰

If the system is foreign controlled, the options available to the US are a bit more difficult to implement. Diplomatic means could be used with a friendly country to convey the seriousness of the potential security breach. This would, however, require the US to be forthright with its operational plans. This operational security (OPSEC) violation may be worse than ignoring the potential problem caused by the imaging system in the first place.

Countermeasures against systems controlled by hostile or indifferent nations is the most serious undertaking. Options range from overt action such as anti-satellite (ASAT) operations to passive concealment and deception activities. ASAT operations would constitute an aggressive action and probably only be used against an adversary. The US has a demonstrated limited offensive capability against low-earth satellites. Passive techniques would probably be the preferred countermeasure, allowing continuation of the operation and maintenance of surprise, albeit at the cost of reduced efficiency. These potential countermeasures are examined in detail in future chapters.

Thesis Questions

This thesis examines current capabilities and trends of unclassified imaging systems to assess their abilities to extract information damaging to the element of surprise during US military operations. It analyzes the importance of surprise, using doctrinal references and case studies, to these operations. It analyzes policy and countermeasure options to counteract this threat. Finally, it combines these three parts together to make an overall assessment of the threat to military operations and make recommendations.

The primary question to be answered is as follows: Can the United States achieve military surprise at the operational and tactical level of war with the continuing proliferation of unclassified satellite imaging systems?

The four secondary questions are as follows: (1) What are the current capabilities and trends in civilian satellite imaging systems

and what operational military utility do they have? (2) What is the element of surprise and how does it support achievement of operational and tactical military objectives? (3) Independent of countermeasures, will the proliferation of remote sensing systems impact surprise? And (4) Given this proliferation, what can the US do from policy and countermeasure perspectives to reduce the effect of these systems on surprise during military operations?

Assumptions, Limitations, and Delimitations

Four assumptions were used during the research and analysis. The first was that the specifications delineated for the proposed satellite imaging systems were feasible and obtainable. All of the systems that pose the most danger to operational security are still in the conceptual and developmental phases. Whether these systems will eventually get built and launched, or once launched that they will resemble their early specifications, is a factor of available resources. The second assumption was that the US government will continue to support policies to assure US technical leadership in the field of earth remote sensing. The aggressiveness of foreign remote sensing programs and the uncertainty of US budgetary commitments places this leadership in jeopardy. The third assumption is that a foreign country, once it has gained access to commercial satellite imagery, will have the necessary image processing and interpretation capability to exploit it for military purposes. The final assumption is that the element of surprise will continue to be an important aspect of US military operations at the tactical and operational levels of war. Existing

doctrine stresses it, but with the new emphasis on force projection versus forward deployment, surprise may only be possible during the strategic deployment and not once forces arrive in theater.

One primary limitation was encountered during the course of conducting the research and analysis. Quantifying the military use of current and proposed civil, commercial, scientific, and media satellite imaging systems is complex. A number of parameters define the information content of the image products from a particular system. These include the following items: spatial resolution (the size of each discrete picture element or *pixel* determines the size target on the earth that can be identified), spectral bands, signal-to-noise ratio, and area coverage, to name a few. Quantifying a specific system's ability to satisfy the quality criteria is a difficult task. One guideline used by national and military imagery interpreters is the National Imagery Interpretation Rating Scale (NIIRS). It provides a methodology to rate a specific image product by the interpreter's ability to extract key information depending on the type order-of-battle being observed (i.e., the ability to discern a particular tank turret in an image product may classify that image as a NIIRS X).²¹

Delimitations used are as follows:

a. The time frame for investigation extends from present time to five years in the future. The rationale is that many of the imaging systems in the concept development phase now will be launched within five years. Predicting capabilities beyond that time period is not feasible.

b. To demonstrate the importance of surprise in warfare, space-era case studies (i.e., 1970s and beyond) are used.

c. Only foreign-controlled systems and domestic-controlled systems with foreign ground stations or licensing agreements are considered in the final analysis.

d. The impact of these unclassified imaging systems are investigated only as they apply to the element of surprise at the operational and tactical levels of war.

e. All work is at an unclassified level. The vast majority of imagery used for intelligence and military applications comes from classified sources and much of the knowledge of the utility of space-based remote sensing data comes from these same sources. Limiting the scope to unclassified systems, products, and applications does not allow comparison to the imagery systems which focus on military applications.

f. Thermal and radar imaging systems are not included in the analysis.

Summary

The effect that the proliferation of unclassified satellite imaging systems has on US tactical and operational military surprise is an extremely important subject, one that has not received much attention from military policy makers and commanders. The modern battlefield is complex enough but, with the introduction of a cheap, readily available source of primary imagery intelligence to an adversary, the operational and tactical commander's job will be even more difficult. This thesis will make policy makers and commanders aware of the current trend in the

proliferation of satellite imaging systems, will identify potential threats to military surprise, and will offer solutions to help counteract the effect on operational and tactical surprise.

Endnotes

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¹³ "Media Satellite Could Complicate Military, Foreign Policy Activities," Aviation Week & Space Technology (June 8, 1987): 22.

¹⁴ Office of the Secretary of Defense, Deputy for Non-Proliferation Policy, International Security Affairs, Proliferation of Space Technology (Briefing Charts) 18 October 1991, 11.

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¹⁶ U.S. Army, FM 100-5, Operations (Washington: Department of the Army, 1993), 2-5; U.S. Air Force, AF Manual 1-1, Volume 1 (Washington: Headquarters U.S. Air Force, 1992), 1.

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CHAPTER 2

LITERATURE REVIEW

No previous work has coupled the proliferation of unclassified imaging systems with the subject of military surprise. However, much has been written individually about the two areas mentioned in the thesis question: imaging systems and military surprise. A third area, potential countermeasures to these imaging systems, is not explicitly mentioned in the thesis question, but may be inferred. If adequate indirect or direct countermeasures can be taken against these imaging systems, the impact of surprise during military operations can be eliminated or minimized. The literature review within this chapter is therefore separated into three areas of focus: the proliferation of unclassified imaging systems with military utility, the relevance of the element of surprise to military operations using case studies, and the potential indirect and direct means to counter the threat posed by these systems to military operational surprise.

Proliferation of Unclassified Imaging Systems

Chapter 1 gave a brief chronological overview of the history of remote sensing and mentioned that the future of remote sensing points to increasing capability. It also gave a cursory glimpse of the proven military applications of current civilian imaging systems. This section, which continues the examination of imaging systems and

applications, is divided into three parts. The first part is a detailed review of the proven military applications, with a focus on applications that are relevant to surprise. The second part is a review of the remote sensing systems which will be on-orbit within the next five years. The final part is a review of the state of knowledge of the use of these new systems.

Proven Military Applications

There has been extensive research and documentation on military applications of civilian remote sensing satellites. According to the Congressional Office of Technology Assessment, "data from civilian satellite systems such as Landsat [sic], but more notably SPOT and the Russian Almaz, have considerable military utility."¹

Several attributes of civilian remote sensing systems have lent themselves very well to military applications. First, unlike national systems, these satellite imaging systems are unclassified. This openness allows much broader dissemination of imagery products down to tactical-level operators. It also allows the militaries of non-space-capable countries access to satellite imagery. Second, civilian remote sensing systems provide simultaneous large area coverage, thus allowing a commander a synoptic view of the battlefield. This large area coverage can provide two useful products. One product is a large area image in digital format that provides a framework for other types of intelligence information to be overlaid and referenced. Another product is a relatively current image map to update existing DMA-provided map products. Finally, most civilian systems have been designed for earth

resources monitoring and are typically multispectral in nature. These multispectral systems are optimized for the analysis of surface materials such as soils, vegetation, and built-up areas. The military has used this unique spectral information to perform such tasks as terrain analysis. These three attributes make civilian remote sensing systems a valuable adjunct to the classified national systems for military applications.

Authoritative documentation on military uses of these unclassified, large-area coverage sources of multispectral imagery is plentiful. The Congressional Office of Technology Assessment published The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications in 1993. This document includes a chapter and an appendix on the subject of military uses of civilian remote sensing data.² It describes a number of militarily-significant applications such as Mapping, Charting, and Geodesy (MC&G), Meteorology, Broad Area Search (BAS), Indications and Warning (I&W), Combat Intelligence, and Arms Control Agreement Monitoring. The Commander of the US and allied air components during the Persian Gulf War, General Charles A. Horner stated that with respect to the LANDSAT and SPOT systems:

Wide-area coverage and responsive map generation capabilities are major contributors to successful mission planning and rehearsal, counterdrug operations, terrain analysis and treaty monitoring. LANDSAT has provided key information during Desert Storm, Somalia and Bosnia operations. We continue to have validated requirements for multispectral imagery data and broad area coverage and are working with the Office of the Secretary of Defense to determine how national and commercial systems can best meet them.³

Thomas G. Mahnken, National security analyst, has written that:

While the resolutions of current commercial observation satellites do not provide imagery that is accurate enough to identify small ground units or individual aircraft, they can detect a number of militarily relevant objects . . .; most reconnaissance and surveillance missions of interest to states in the developing world--such as locating troop concentrations and the construction of new military facilities--could be accomplished using imagery from commercial satellites. SPOT imagery has been used to monitor such militarily significant sites as the Israeli nuclear facility at Dimona; the Golan Heights; the Mitla Pass in the Sinai; the Fao Peninsula, Basra, and the Shatt al-Arab in the Persian Gulf; and Mirpur and Muzaffarabad on Pakistan's borders.⁴

Jeffrey T. Richelson, the noted author on intelligence community affairs, has written that "certain types of relevant military activity can be detected and identified by commercial satellites...[including] airfields, missile fields, runways, ports, and aircraft carriers."⁵ Finally, the Deputy for Non-Proliferation Policy and International Security Affairs within the Office of the Secretary of Defense produced a briefing in October 1991 titled Proliferation of Space Technology which stated that:

Landsat's [sic] multi-spectral capability serves multiple military planning and operations requirements. Virtually all of the spectral regions included in civil systems (combined with specific resolutions) can support military tasks. For example, multi-spectral capabilities for vegetation analysis can also be used to support military terrain delimitation analysis and camouflage detection tasks. LANDSAT imagery is currently being used to support Strategic Air Command mission-critical requirements.⁶

All of these quotes show that people inside and outside of the government are aware of and have documented the extensive use of commercial imagery by the military.

Not all of these applications are relevant to the thesis topic. While MC&G, broad area search, meteorology, arms control agreement monitoring, and area delimitation are all important applications, the

only ones of significance for this thesis are those concerned with tactical and operational surprise: Indications and Warning (I&W) and Combat Intelligence. Indications and Warning can be described as:

those intelligence activities intended to detect and report time-sensitive intelligence information on foreign developments that could pose a threat to . . . military, political, or economic interests. . . . It includes forewarning of enemy actions or intentions; the imminence of hostilities; insurgent or other attack.⁷

One might be critical of the utility of currently available remote sensing data for an I&W task which not only requires relatively high spatial resolution, but also frequent revisits over a given target. Though current systems are not optimized for this application, it has been done in limited instances using change-detection image processing techniques. In one demonstrated case, Allan V. Banner performed a study for the Canadian government: he analyzed commercially available SPOT imagery of the Kabul airport and a nearby military encampment and detected the movement of aircraft and trucks from these areas.⁸

Unlike I&W which focuses on the monitoring of such fixed locations as choke points, crossroads, garrisons, airfields, and naval ports, Combat Intelligence focuses on the sharply delimited area of the battlefield.⁹ Though unable to detect individual dispersed vehicles, current commercial imagery can provide valuable activity indication. An example is that "DIA [Defense Intelligence Agency] has stated that 'during preparations for the ground war during Operation Desert Storm, 30-meter Landsat [sic] could have revealed ground scars and track activity indicating the thrust into Iraq west of Kuwait.'"¹⁰ The ultimate conclusion is that Indications and Warning is a demonstrated

application for remote sensing data primarily at the operational and strategic levels of war, while Combat Intelligence applies primarily to the tactical and operational levels. Both applications directly impact the element of surprise.

Future Remote Sensing Systems

Future remote sensing systems can be classified in two general categories: those that are extensions of existing imaging systems or are currently being built (programmed systems) and those that stem from new concepts and new consortiums that are as yet unproved or unfunded (proposed systems). Both types of systems share one thing in common: they are being developed as commercial enterprises. Remote sensing systems are no longer built solely for scientific applications or to demonstrate national technological capabilities. Earth-remote sensing is big business, and it is growing even bigger. In 1992, the combined annual commercial satellite imagery sales of the industry's two biggest operators, SPOT (France) and EOSAT (US), was nearly \$100 million, and growing at a rate of 20-30 percent per year.¹¹ Some industry officials believe that the growth rate for all imagery providers will be much higher and that "by [the year] 2000 there will be a worldwide industry with revenue of as much as \$15 billion providing pictures to mapmakers, environmentalists, oceanographers, urban planners and utilities."¹² This projected market ignores two potentially lucrative markets: non-space capable foreign militaries and intelligence organizations and the media. This vast market to provide the raw imagery data to feed the requirements of a growing number of users with ever-improving image

processing capabilities has caught the attention of numerous companies, consortiums, and governments willing to invest the resources to capture their perceived fair share.

Documentation on these programmed and proposed commercial imaging systems ranges from magazine articles to government briefing charts to company-provided literature. Specification information available for the programmed systems is obviously more credible due to their heritage and/or the resource commitment of their developers. However, the feasibility of the proposed systems should not be underestimated.

With the launch failure of the LANDSAT 6 remote sensing satellite in 1993 and the Department of Defense withdrawal from the LANDSAT 7 program (now NASA-managed with projected capabilities similar to LANDSAT 6) later that same year, the French and the Russians now dominate the realm of programmed commercial imaging systems with improved capabilities.¹³ The SPOT 3 satellite was successfully launched in September 1993 and has the same 10-meter panchromatic and 20-meter multispectral imaging capability of its predecessors. SPOT 4, currently being built and scheduled for launch in 1997, will have similar spatial resolution. The true breakthrough in capability for SPOT will occur with the launch of SPOT 5 in 1999. This system will be capable of imaging to a 5-meter panchromatic and 10-meter multispectral spatial resolution.¹⁴

When compared to some of the proposed systems mentioned later in this chapter, the SPOT 3 through 5 spatial resolution specifications may not seem very impressive. However, it must be kept in mind that the

SPOT program is an ongoing, funded and commercially viable program with a strategy of gradual improvements designed to allow new imagery data to be compared to data from previous generations. This comparison allows users to observe changes to the earth's surface over time. A significant increase in spatial resolution from ten meters to one meter, for example, would render the millions of scenes collected by previous satellites obsolete for comparison purposes.

Russia's current contribution to commercial remote sensing is derived from the KFA 1000 camera carried onboard the Resurs military reconnaissance satellites. Although of a higher spatial resolution than other commercially available products (5-meter panchromatic), Resurs relies on photographic film returned from space in canisters rather than electronically transmitted digital imagery.¹⁵ The Russians plan to develop a new commercial digital remote sensing system with a 5-meter spatial resolution in the late 1990s.¹⁶

On paper, the proposed remote sensing systems are much more capable than the programmed systems just mentioned. A list of three systems and their specifications proposed by US corporate teams is shown in Table 1.

A quick analysis of these remote sensing systems with respect to those currently available shows some important improvements in two of the key parameters outlined in Chapter 1. Spatial resolution will improve from the current 10-to-15-meter range to the 1-to-3-meter range for panchromatic bands and from the 20-to-30-meter range to the 4-to-15-meter range for multispectral bands. Revisit timeliness will improve from a 3-to-26-day access to a 2-to-3-day access. Since 1-meter spatial

TABLE 1

SPECIFICATIONS FOR THREE PROPOSED COMMERCIAL REMOTE SENSING SYSTEMS

SYSTEM	Eyeglass	CRSS	Worldview
COMPANIES	GDE, Orbital Sciences, Itek	Lockheed	Worldview, CTA
RESOLUTION	1-meter pan	1-meter pan 4-meter MSI	3-meter pan 15-meter MSI
ALTITUDE	700 km	680 km	476 km
REVISIT	2 Days	3 Days	2.5 Days 2 Satellites
SCENES/DAY	180 (15x15 km)	??	??
NO. BANDS	1 (pan only)	4-5 (pan+MSI)	4 (pan+MSI)
GND STATIONS	US&Foreign	CONUS&Alaska	CONUS, Alaska, Europe
POINTING	??	Along & Cross Track	Along & Cross Track
INITIAL OPS	Early 1997	1997	Late 1995
SCENE PRICE	\$1600	Below aerial photography	\$1300-\$1700

Source: Central Imagery Office Briefing Charts, "Commercial Remote Sensing - Systems Specifications" ¹⁷

resolution from space-based systems is no longer state-of-the-art¹⁸ and because cross-track pointing to achieve quicker revisit has been proven on commercial systems, all three of the systems shown in the table are feasible with current technology. The specifications proposed by these consortiums should therefore be considered reliable.

Projected Applications of Future Systems

With the improved technical specifications of the future remote sensing systems comes the ability to perform a greater number of missions. The improvement of spatial resolution to the 1-to-3-meter range opens up a whole new realm of civilian and military applications.

On the commercial side, the three presidents of the companies developing the EYEGLASS system shown in Table 1 have stated:

The availability of near-real-time, high-quality digital terrain map information will drive a rapid expansion of the software technology that uses this information. . . . Soon, digital map users will rapidly and effectively assess and analyze demographics, survey and utilize scarce resources, conduct detailed strategic commercial planning on a neighborhood or global scale, or, when the unfortunate situation necessitates, monitor natural disasters and coordinate recovery efforts. . . . An accurate nationwide digital contour map will serve as a foundation for protecting the environment and considering the environmental impact of future projects. The digital maps of the future will be an interactive part of our national information highway at the fingertips of all Americans.¹⁹

The three panchromatic images (taken from airborne sources) in Figure 1 show the US Capitol Building in Washington, D.C. The only difference between the three is the spatial resolution. The spatial resolution of the left image is one meter, representative of the proposed Eyeglass system. In this image, individual sections within the rotunda are visible. The spatial resolution of the center image is three meters, representative of the proposed Worldview system. Some sharpness apparent within the one-meter scene has been lost, but the general shape of the rotunda can still be determined. The right image has a spatial resolution of ten meters, similar to the current SPOT system. This image appears very blocky and only the general shape of the building can be detected. These examples graphically demonstrate the qualitative assessment possible in determining the utility of various satellite imaging systems.

U.S. Capitol, Washington, D.C.

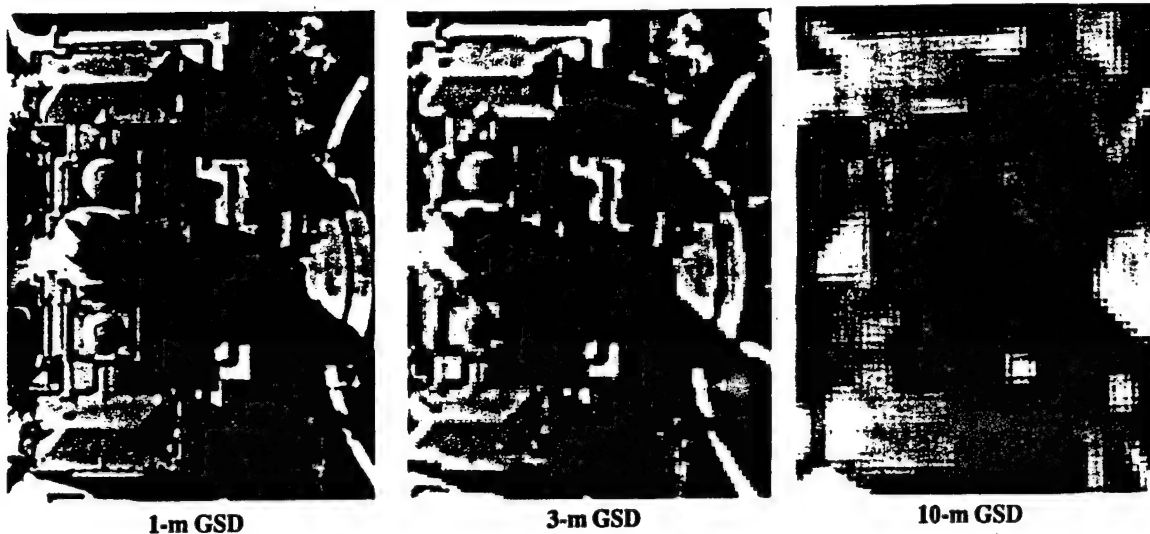


Figure 1. US Capitol, Washington, D.C.

Source: Testimony to the House of Representatives by James H. Frey, Dr. Terry A. Straeter and David W. Thompson on 9 February 1994.²⁰

There is extensive information available on the potential military applications for these advanced remote sensing systems. From a purely quantitative approach, imagery in the 1-to-3-meter range can be used for a wide variety of interpretation tasks not feasible with coarser resolution imagery. This quality of imagery allows the detection and identification of communications facilities, supply dumps, troop units, aircraft, command and control headquarters, missile sites, nuclear weapon components, and individual vehicles.²¹ These targets are the types required to conduct I&W and Combat Intelligence tasks; therefore, the detection and identification of these targets is relevant to the thesis.

The 30-meter spatial resolution of the LANDSAT satellites (nine times coarser than the 10-meter scene shown in Figure 1) has proven useful for such tasks as the detection of man-made water barriers and defensive fortifications during the Iran-Iraq war.²² The revisit timeliness of LANDSAT has also proven adequate for many tasks. One well known example is the use of LANDSAT to image the Chernobyl nuclear plant accident in the spring of 1986. Two images collected over the same area on different days, 21 March and 29 April, were used to perform change detection with great success.²³ However, for many I&W and Combat Intelligence tasks, these performance characteristics are woefully insufficient. A RAND study concluded that "although Landsat [sic] was found to be of great use during the Gulf War, its utility was diminished by its relatively low spatial resolution, . . . and its long revisit times."²⁴

This diminished utility will not be the case with the proposed systems. According to the Deputy for Non-Proliferation Policy within the Office of the Secretary of Defense, these new systems will have the spatial resolution and timeliness to perform Current Intelligence. Current Intelligence is closely related to I&W and Combat Intelligence and includes such tasks as "distinguishing between general types of aircraft on the ground, identifying tanks in a column of vehicles, and determining whether silo doors are open or closed. . . ."²⁵ By the mid-to-late 1990s, civilian remote sensing systems will be operating with a combination of relatively high spatial resolution and relatively rapid data delivery times. The synergistic combination of these two elements

will allow this next generation of satellites to perform increasingly more capable military intelligence functions.²⁶

Relevance of Surprise to Military Operations

Chapter 1 included a review of doctrinal references about the element of surprise in warfare. This section does not repeat that information but instead focuses on the literature available to support the case study methodology discussed in the next part of the paper, Chapter 3. The three primary case studies used to understand surprise are Operation El Dorado Canyon, Operation Just Cause, and Operation Desert Storm. All three deal with the operational and tactical levels of warfare, but differ by scope and type of forces used. In addition to text references, interviews were conducted with US Air Force and US Army officers that participated in these operations.

Operation El Dorado Canyon

The first case study is Operation El Dorado Canyon, the retaliatory air strike by the United States against Libya in April of 1986. Despite the involvement of a massive air armada of twenty-nine F-111 and EF-111 aircraft and twenty-eight aerial refueling tankers launched from England and two US Navy aircraft carriers based in the Mediterranean, the Libyans were caught by complete surprise. Even after notification by Maltese radar operators, the Libyans paid no heed to the imminent attack.²⁷ This surprise is graphically demonstrated in the following description by Brian L. Davis:

The pilots were amazed to see that the street lights were on in both cities; they remained on throughout the attack. Runway lights shone, as well as floodlights around the principal buildings and

the minarets of the central mosque in Tripoli, which provided a beacon for the U.S. planes. No air raid alarms sounded, no instructions on what to do in an air attack had been given to the populace, there was no curfew, and cars were driving with their headlights bright.²⁸

Analysis of this raid provides insight into the relevance of surprise to an air-only campaign.

Operation Just Cause

The invasion of Panama during Operation Just Cause in December of 1989 was an excellent example of operational surprise. In fact, one of the key principles that the Commander in Chief Southern Command Operations Order 1-90 (code named BLUE SPOON) was built upon was maximum surprise.²⁹ That surprise was achieved with such a large, quickly deployed ground force is startling. Approximately 4,500 troops were deployed from the CONUS to link up with 7,000 troops already in Panama to strike twenty-seven targets simultaneously at H-hour. Eighty-four parachute missions and twenty-seven air-land missions were flown into Panama with the initial forces.³⁰ That the Panamanians did not detect the loading and deployment of 111 aircraft from the CONUS is testament to the level of surprise achieved. Reasons given for this success range from the use of a night operation to the desensitization of the Panamanians.³¹ This case study is very relevant to the analysis of remote sensing and surprise during a light-force operation.

Operation Desert Storm

Operation Desert Storm provides another excellent case study for the analysis of the element of surprise at the operational level of warfare. The deception used by the allied forces to focus the attention

of Iraq to the east coupled with Iraq's lack of reconnaissance assets allowed surprise to be attained by the left flank turning movement.³²

According to Dr. Thomas M. Huber:

The surprise element in the US attack derived in part from the Iraqi's failure to recognize the maneuver capabilities of the coalition forces across the open desert. To attack from the west meant attacking across the desert, and few Iraqi staff officers believed US forces could operate freely across that featureless terrain. Schwarzkopf's planners also took advantage of the limited observation capabilities of the Iraqis by applying the coalition's superior air power, beginning on 17 January 1991. Coalition air forces systematically destroyed the capabilities of the Iraqi Air Force, thus making it almost impossible for the Iraqis to observe the disposition of US and coalition forces. Only after the Iraqi Air Force was neutralized did the repositioning of coalition assets begin.³³

In addition to the surprise achieved by ground forces, the length and magnitude of the air campaign also caught Iraq by surprise. Saddam Hussein believed that his air defenses and passive defensive measure such as hardening of high value targets, dispersed and dug-in forces, and hiding of mobile assets would protect his forces from coalition air power.³⁴ Iraq did not anticipate the extent that the allied forces would rely on air power to decimate its military. As with the surprise ground maneuver, the lack of intelligence collection capability restricted Iraq's ability to assess the magnitude of the air forces arrayed against it. This case study provides insight into the use of surprise during a major heavy-force operation.

Other Information on Surprise

In addition to the three case studies above, other relevant information on the element of surprise is available. According to Major Jeffrey O'Leary, "strategic surprise is difficult to prevent, even in

the face of accurate and timely intelligence (including overhead imagery), because it is based on exploiting a leader's or nation's personality and characteristics as well as the bureaucracies that serve them."³⁵ Although his thesis focuses on strategic surprise, several issues and case studies that he discusses are applicable to operational and tactical surprise. Two relevant issues are the lack of knowledge by the enemy and the use of strategic surprise as a force multiplier. Two relevant case studies are the invasion of Kuwait by Iraq in 1990 and the Cuban Missile Crisis.

Some effort on the quantification of the element of surprise in warfare has been done. From analysis of the Arab-Israeli wars of 1967 and 1973, Colonel Trevor N. Dupuy has written that:

My colleagues and I have made preliminary and tentative qualified comparisons of the effects of surprise on the relative combat effectiveness of the opposing forces in both the 1967 and 1973 Wars, in comparison with the effectiveness of each in battles in which there was not surprise. On the assumption that the effects of surprise were primarily in the relative mobility and relative vulnerability of the opposing forces, the combat capability of the side achieving surprise was--on the average--almost doubled.³⁶

Whether or not surprise doubles the combat capability of a force, it appears to be conclusive that great emphasis is placed on achieving surprise in warfare.

Countermeasures

The final part of the thesis deals with the policy measures and countermeasures that can be taken by the US to minimize the impact due to the proliferation of civilian remote sensing systems. On the policy side, relevant information exists on the current public law and

administration policies that govern the development, export, sales, and operations of advanced satellite imaging technology. One source is a directive signed by President Clinton in March of 1994 which gave approval to US satellite firms to sell high-quality satellite photos.³⁷ One common theme to the literature in this area is the government's need to balance between protecting national security and promoting free enterprise by American companies in an internationally competitive marketplace.³⁸

For countermeasures, both passive and active means are available to the US to minimize the impact on surprise during military operations. Passive means include such doctrinal or procedural activities such as restricting operations to times when the imaging satellite is not overhead or when it cannot image effectively (e.g., during nighttime or under heavy clouds for electro-optic systems) or using cover, concealment, and deception practices (CC&D). Active means include the use of anti-satellite (ASAT) weapons to destroy the remote sensing satellite.

Relevant literature is available on anti satellite weapons and their use to counteract remote sensing satellites. The Air Force developed an ASAT system in the 1980s which was ultimately canceled. The Army has a development program currently underway. Whether the Army system will ever be deployed depends on Congressional interpretation of the 1972 Anti-Ballistic Missile Treaty. US officials have warned that potentially adversarial nations have learned of the value of remote sensing satellites from the Persian Gulf War and that the US must have an ASAT capability to maintain the advantage.³⁹

Major James G. Lee's thesis on counterspace dominance discusses ASAT options that can be used against nations with various levels of space capability. His summary states that "regardless of the inherent military utility a civilian satellite may possess, the military benefits of destroying a civilian satellite must be weighed against the potential political backlash created by intentionally targeting and destroying a nonmilitary system."⁴⁰

Summary of Literature Review

The literature review has uncovered a wealth of information critical to the thesis. While no single source focusing on the thesis topic has been found, literature on the three discrete sub-topics is readily available. The three areas relevant to the thesis are (1) the proliferation of unclassified imaging systems with military utility, (2) the element of surprise in military operations, and (3) the potential indirect and direct means to counter the threat to surprise posed by these systems.

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CHAPTER 3

RESEARCH METHODOLOGY

The design of the thesis research methodology focuses on the primary question being answered: Can the United States achieve military surprise at the operational and tactical level of war with the continuing proliferation of unclassified satellite imaging systems? To support this question, there are three phases to the research methodology corresponding roughly to the three secondary thesis questions. Each of these phases uses a research pattern selected and tailored specifically not only to answer its respective secondary question, but also to tie the result to the previous secondary question. Using this methodology, due to the pyramid structure of the questions, the thesis question also will be answered. This chapter explains how these research patterns have been adapted to answer the thesis questions and provides insight into the details of the research design.

Phase One--Case Study Methodology

Multiple case study methodology is used during Phase 1. Case studies "illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result."¹ In this situation, several distinct case studies are analyzed to determine how surprise impacted the results.

The components of the case study research design come from the book Case Study Research by Robert K. Yin. He defines research design

as "the logical sequence that connects the empirical data to a study's initial research questions and, ultimately, to its conclusions" or as "an action plan for getting from here to there."² He lists the necessary five components as follows: a study's questions, its propositions, its units of analysis, the logic linking the data to the propositions, and the criteria for interpreting the findings.³

For this phase, the secondary question addressed is: What is the element of surprise and how does it support achievement of operational and tactical military objectives? The proposition is that surprise is a necessary element of warfare because it acts as a force multiplier by allowing the massing of overwhelming combat power versus an enemy's weakness in not allowing the enemy time to react. The units of analysis are the events (e.g., the Desert Storm left-hook) where surprise was used successfully. Linking data to propositions is done by the use of pattern matching, as described by Yin, "whereby several pieces of information from the same case may be related to some theoretical proposition."⁴ In this case, the anticipated pattern shows that surprise greatly contributed to the success of the operations. The criteria for interpreting the findings is necessary only if two conflicting patterns emerge. As will be seen during analysis in Chapter 4, this step is not necessary.

Analysis of Operation El Dorado Canyon (Libya), Operation Just Cause (Panama), and Operation Desert Storm (Iraq) provides some solid evidence of the importance of surprise at the operational and tactical levels of war. The intent is to establish a factual baseline on the use of surprise.

Unclassified imaging systems that were available during the above conflicts were not as capable as the programmed and proposed systems discussed in Chapter 2. However, an speculative analysis of the projected effects of these future imaging systems on these case studies is conducted in the causal relationship research section of Chapter 4.

Phase Two--Measurement Research

Measurement research methodology is used during Phase 2. Measurement research focuses on several dimensions and measures them systematically and in great detail. According to Julian L. Simon and Paul Burstein in their book Basic Research Methods in Social Science, "measurement research seeks to establish the magnitude or size of a phenomenon on one or more of its dimensions."⁵

During this phase, the secondary question addressed is as follows: What are the current capabilities and trends in civilian satellite imaging systems and what operational military utility do they have? This question lends itself well to quantitative assessment. As discussed in Chapter 2, remote sensing systems have operational parameters which determine their utility for various applications. By establishing performance criteria linked to these parameters, the relative goodness of these systems is established.

As stated by Simon and Burstein, "deciding *what to measure* and how to draw the definitional boundary lines around the quantity to be measured--translating the theoretical (hypothetical) concept into empirical terms--is a crucial decision in measurement research."⁶ The selection of these criterion must be based on the attributes necessary

to make a civilian remote sensing system useful to a foreign military for Indications and Warning (I&W) and Combat Intelligence tasks. Three criterion are considered in detail: accessibility, timeliness, and quality.

The first criterion is accessibility. For a source of imagery to be of use to a potential adversary, he must be able to obtain the product in a usable form. Methods to obtain it could be either direct purchase, purchase via a third-party agent, or obtaining it directly from the public domain (e.g., media). Imagery sources that will be protected in some way during a crisis or war via policy, technical restriction, or classification will not be as much of a problem as those sources that are unconstrained.

The second criterion is timeliness. An adversary must be able to obtain the imagery while it is still of military significance. The rapid pace of the modern battlefield stresses maneuver and momentum. In most cases, forces do not stay stationary for extended periods of time. The collection and exploitation intelligence functions that support the detection and identification of enemy forces or their activity indicators, defined in Chapter 2 as Combat Intelligence, must be done rapidly. In other words, remote sensing products must be obtained in near real-time.

The final criterion is quality, which may be defined in terms of spatial and spectral resolution and area coverage. An imagery product with such a coarse spatial resolution that desired target objects cannot be discerned from the background is of very limited military use. As mentioned in Chapter 2, a relatively high spatial

resolution is necessary to detect individual vehicles. Also, if an imaging system sensor only collects within a specific spectral bandwidth (e.g., long-wave infrared for geological applications), it may be of limited or no use for the collection of military targets. Finally, if the system's area coverage is very small, the target of interest may be missed during collection.

These three criterion (accessibility, timeliness, and quality) are shown in matrix format in Table 2. During the thesis analysis in Chapter 4, programmed and proposed commercial imaging systems are inserted into a similar matrix, measured versus the performance standards, and then categorized as either meeting or not meeting a given threshold (determined during analysis). Those systems whose specifications meet the criteria thresholds are carried forward to the next phase.

Phase 3--Relationship Research

Relationship research is the methodology used in Phase 3.

According to Simon and Burstein:

Relationship research attempts to determine whether there is an association between two phenomena. This may be to aid prediction, or to determine whether one variable can be used as a proxy for the other, or it may be a prelude to determining a causal relationship.⁷

During this phase, analysis of two causal relationships will be conducted. The first is a speculation as to the effect of the remote sensing systems discussed in Phase 2 on the element of surprise in the case studies discussed in Phase 1. The second is an examination of the

TABLE 2

EXAMPLE OF POTENTIAL CRITERION MATRIX USED TO SUPPORT MEASUREMENT
RESEARCH PHASE

CRITERIA	PERFORMANCE LEVELS	SYSTEM #1	SYSTEM #2	SYSTEM #3
Accessibility	Available to All Potential Hostile Countries Due to Foreign Ownership or Over- seas Ground Stations?			
Timeliness	Worst Case Revisit to Any Area on the Globe: Less than 24 Hrs? 24-72 Hrs? Greater than 72 Hrs?			
B Quality	Best Spatial Resolution: Less than 1 meter? 1-3 meters? Greater than 3 meters? Spectral Bands Available: Pan Only? MSI? Area Coverage: Less than 10x10 km? Greater than 10x10 km?			

Potential for various countermeasures to counteract the threat to surprise.

The first causal relationship analyzed ties surprise to the issue of remote sensing by answering the secondary question: Independent of countermeasures, will the proliferation of remote sensing systems impact surprise? From the baseline established in Phase 1, a

new speculative look is taken at the case studies by introducing the intelligence information that could have been extracted from commercial imaging systems. In other words, would the availability of good quality commercial remote sensing data in a timely manner have allowed the enemy to anticipate a surprise attack and counteract the massing of overwhelming combat power.

For the second causal relationship, the issue of countermeasures, the relevant secondary question is as follows: Given the proliferation of unclassified satellite imaging systems with military utility, what can the US do from policy and countermeasure perspectives to reduce the effect of these systems on surprise during military operations? The analysis will therefore attempt to predict a causal relationship between the act of performing countermeasures and its effect on eliminating the threat posed by imaging systems to surprise. In this analysis, the first phenomenon is used as a predictor of the second phenomenon by establishing a pattern of variation between the two. For example, if a countermeasure to conduct operations only at night is enacted and the selected imaging system can detect objects only in the day, a causal relationship pattern has been established. Once again, the three case studies are used as a baseline.

The two areas to be analyzed are policy issues and active and passive countermeasures. Policy issues focus on the current public law that governs the development, export, and operations of advanced satellite imaging technology. Finding this information is easy. The difficult part comes in extrapolating how the government will implement this policy, given the need to balance between protecting national

security and promoting free enterprise by American companies in an internationally competitive marketplace. Also included within the realm of policy measures are the diplomatic and economic means that may be taken to influence allied nations to restrict access to their unclassified imagery products during a crisis.

Analysis also examines the passive and active means available to the US to minimize the impact on surprise during military operations. Passive means could include such doctrinal or procedural activities such as restricting operations to times when the satellite will not be overhead or when it cannot image effectively (e.g., during nighttime or under heavy clouds for electro-optic systems) and using cover, concealment, and deception practices (CC&D). Active means could include such techniques as anti-satellite (ASAT) operations and the use of directed energy weapons (DEW) to blind the satellite payload's focal plane.

Chapter Summary

The purpose of the thesis research methodology outlined above is to answer the secondary questions and ultimately the primary thesis question. To support this purpose the research methodology is divided into three phases. Each of these phases uses a specific research pattern selected and tailored to address the questions being answered. The next chapter shows the analysis done to answer the secondary and eventually the primary questions using the research methodology described above.

Endnotes

¹ Robert K. Yin, Case Study Research, Design and Methods Revised Edition (Newbury Park: Sage Publications, 1991), 22-23.

² Yin, Case Study, 29.

³ Yin, Case Study, 28.

⁴ Yin, Case Study, 33.

⁵ Julian L. Simon and Paul Burstein, Basic Research Methods in Social Science 3rd. Edition (New York: Random House, 1985), 41.

⁶ Simon and Burstein, Basic Research, 41.

⁷ Simon and Burstein, Basic Research, 49.

CHAPTER 4

ANALYSIS

The thesis analysis follows the pattern outlined in Chapter 3: case study methodology, measurement research, and relationship research. The overall concept of the analysis first establishes a factual baseline for the importance of surprise to military operations by examining three case studies. The next step quantitatively assesses remote sensing systems and determines their military utility for I&W and Combat Intelligence tasks. Finally, speculation on causal relationships determines the impact of these remote sensing systems on surprise and the negating effect of potential countermeasures.

Case Study Analysis

Operations El Dorado Canyon, Just Cause, and Desert Storm provide three examples of the use of surprise during US military operations. For each of these cases, Yin's case study methodology encompassing a question, a proposition, units of analysis, pattern matching to link data to propositions, and criteria for interpreting the findings (only if two conflicting patterns develop) is used.

Operation El Dorado Canyon

As with all of the case studies, the question to be answered is as follows: What is the element of surprise and how does it support achievement of operational and tactical military objectives? El Dorado

Canyon, the US attack on Libya in April 1986 in retaliation for its sponsorship of terrorism, provides an excellent example of tactical surprise achieved during an all-air operation. As mentioned during the literature review in Chapter 2, the actions of the Libyans leads one to conclude that massive air strikes caught them by complete surprise.

The proposition (answer to the question) for El Dorado Canyon and the other case studies is that surprise was a critical element of warfare, because it allowed the massing of overwhelming combat power against the enemy's weakness and did not allow the enemy time to react. From this proposition comes three units of analysis: the planning and execution of the mission to obtain surprise, the achievement of surprise, and the results.

The planning process for El Dorado Canyon was clearly oriented toward achieving surprise.¹ According to Major Tony Kern, a KC-135 pilot involved in the planning and execution of the aerial refueling support out of RAF Mildenhall, great lengths were taken to maintain operational and tactical surprise. Radio silence was maintained, electronic emissions control was implemented, and the operation was conducted under the cover of darkness.² According to Major Jeff Hodgdon, an F-111 weapons system operator who was involved with targeting and tactics planning at RAF Lakenheath:

We believed surprise to be essential to mission success . . . surprise offered the ability to quickly mass our attacks on an unsuspecting enemy . . . we timed our attack to be congruent with a planned Salty Nation Exercise, so as to avoid unwanted attention. . . the entire mission, up to tanker rendezvous after attack, was flown comm-out . . . Have Quick radios were used if needed.³

Surprise was clearly viewed as critical to the success of the mission.

This attention to the element of surprise was well rewarded with the Libyan lack of preparedness. Major Michael A. Snodgrass stated in his thesis on tactical fighter employment that tactical surprise was achieved. This fact was evidenced by several factors: the lights of Tripoli were on and remained on for some time, the Libyan Air Force did not have any interceptors airborne and did not launch a single fighter during the attack, and the Libyans had their IL-76 transports lined up wingtip to wingtip at a single airfield.⁴

The results of the operation were good. Out of over a hundred aircraft involved, only a single F-111 with its crew was lost. Apart from this loss, the bombing runs of six out of seventeen F-111s and three out of fifteen A-6s involved in the actual raid had to be aborted due to either equipment malfunction or pilot disorientation. This loss of bombing sorties was not critical due to the redundancy built into the mission.⁵ The air crews that did participate in the actual bombing of targets accomplished their mission. According to the exploitation of photographs taken by SR-71 reconnaissance aircraft, all five targets struck by both Air Force and Navy aircraft during the operation were severely damaged.⁶ At one target of note, the Tripoli Airport, "European diplomats on the ground reported that at least ten IL-76s were badly damaged and ten to fifteen helicopters were disabled."⁷ As stated by Major Snodgrass, "Operation El Dorado Canyon was a tactical success."⁸

From the preceding units of analysis, some direct matches can be made between the factual data and the proposition. In keeping with the doctrinal references cited in Chapter 1, the element of surprise at

the operational and tactical levels was planned for and executed by the US military during El Dorado Canyon. Surprise was achieved as demonstrated by the unpreparedness of the Libyans in protecting potential targets and scrambling fighters. This unpreparedness led directly to the success of the mission in terms of target damage and minimal friendly casualties, respectively. Therefore, in the case of this air strike, the proposition holds true that surprise was a critical combat multiplier that allowed the massing of combat power with minimal enemy response.

Operation Just Cause

Operation Just Cause was the US invasion of Panama in December of 1989. Its purpose was to protect American citizens, ensure the security of the Panama Canal, destroy the combat capability of the Panamanian Defense Force, and apprehend and extradite Panamanian leader Manuel Noriega.⁹ Just Cause provided a good example of how surprise can be used in an operation involving a large number of light forces. The question to be answered, the proposition, and the three units of analysis (the planning and execution of the mission to obtain surprise, the achievement of surprise, and the results) remain the same as in Operation El Dorado Canyon.

The planning and execution of Just Cause sought to achieve surprise at the tactical level. The Panamanian leadership probably knew that an invasion by the US was imminent; however, they did not know the precise date and time of the attack. In addition to the rapid deployment of US-based troops and aircraft mentioned in Chapter 2, the

US hoped to achieve this tactical surprise by desensitizing the Panamanians through repetition of certain training exercises, by the concealment of major equipment when it arrived in-country, and by the use of night training and operations. US military planners conducted a slow, steady growth in the number of forces in Panama and gradually increased the training level of those forces prior to H-Hour. They desensitized the Panamanians with continuous single-unit exercises called "Sand Fleas" and joint exercises called "Purple Storms," one of which involved an air assault from Howard AFB to Fort Amador focused on specific Just Cause objectives.¹⁰ According to Major Sam Johnson, the Fire Support Officer for the 2/75 Ranger Battalion, in order to deceive the Panamanians and the Cubans his entire unit made a feint from Fort Benning out over the Caribbean and returned, days prior to their actual launch for the operation.¹¹

In addition to desensitization, US planners hoped to achieve tactical surprise by the concealment of major equipment brought into country. Days before the invasion, twenty Army MH-6/AH-6 Special Operations Forces scout/attack helicopters and several Air Force MH-53J Pave Low and MH-60 Pave Hawk Special Operations helicopters were flown in aboard C-5 transports or under their own power, under cover of darkness, and hidden away in hangars until the twentieth.¹² In November, four Sheridan tanks were secretly deployed to Panama aboard a C-5. These tanks were only exercised at night to avoid detection.¹³

In addition to the Sheridan tank crews, the remainder of the American forces achieved tactical surprise by training almost exclusively at night and ultimately by launching the invasion under

cover of darkness. With the widespread use of night vision goggles, the US could train at times when their intentions could not be observed by the Panamanian Defense Force (PDF). In his account of how the invasion of Panama worked, Robert R. Ropelewski stated, "six AH-64 Apache attack helicopters were brought into Panama in late November, but were kept in a hangar during the days . . . the Apaches were flown every night, however, observing some of the same sites that later became the objectives in Operation Just Cause."¹⁴ Prior to the December 20th invasion, Major Johnson's Ranger unit trained almost exclusively at night, conducting three practice airfield seizures under the cover of darkness.¹⁵ For the actual invasion of Panama, he stated that "night operations were critical . . . the Macho de Montes (Panamanian 7th Infantry Battalion) had four optically-sited ZPU-23-4s protecting the runway, no night vision capabilities, and limited tracer for crew-served weapons . . . night was essential to our success."¹⁶

Was surprise achieved in Operation Just Cause? In most cases, surprise seems to have been achieved at the tactical level. Limited examples show that the Panamanians knew that action was imminent. By mid-December, convoys of PDF buses were moving back and forth across the Bridge of the Americas full of troops.¹⁷ Immediately before the attack, the PDF company commander at Fort Amador brought in additional troops to defend the fort, much to the dismay of US forces who relied on surprise to seize this critical target from the Panamanians.¹⁸ However, for the most part the PDF was caught off guard. One example of their shock occurred early in the morning on the twentieth of December at the Tocumen military airfield. Members of the Panamanian Air Force sitting

in the control tower received a frantic call stating that "The Americans are invading Panama! La Comandancia is under attack!"¹⁹ In another example relayed by Major Johnson:

Cuba was prepared and had established close ties with Noriega to provide early warning. Their radars lit on us like a Christmas tree as we went past. The info made it to Panama, but no one believed it. When we seized the [Noriega's] beach house, the message "The Americans are coming" was on the FAX machine in Noriega's bedroom. . . . We surprised them so much that we captured soldiers in the showers. They were only capable of getting one V-150 [armored vehicle] out of their motorpool. We captured over 650 prisoners in the first four hours.²⁰

Tactical surprise was clearly achieved in most cases.

As with Operation El Dorado Canyon, the results of Operation Just Cause were favorable to the US. All four of the stated objectives were achieved: American citizens were protected, the security of the Panama Canal was ensured, the combat capability of the PDF was destroyed, and Manuel Noriega was apprehended and extradited to the United States. The Panamanians had been given a new start without the PDF:

By eliminating the PDF, Just Cause removed the institution that controlled Panamanian political life. . . . [This removal] offered Endara and his country a blank page upon which to compose a new, more democratic and just society. It will take years to write the score, but without Just Cause, it may never have been conceived.²¹

For an operation involving approximately 18,000 US troops, casualties on both sides were remarkably light. A total of twenty-three US soldiers and three American civilians died during Just Cause. Another 324 were wounded in the conflict. Over 300 Panamanian soldiers and more than 200 civilians were also killed. However, the majority of Panamanians believed that the invasion of their country by the US was worth the cost.²²

As with the first case study, the units of analysis for Just Cause lead to some direct matches between the factual data and the proposition. Using rapid CONUS deployment, desensitization through repetition, concealment, and nighttime training and operations, surprise at the tactical level was planned for and executed by the US military during Just Cause. Tactical surprise was achieved as demonstrated by the unpreparedness of the Panamanians upon the arrival of American forces. This unpreparedness led directly to the success of the mission in terms of fulfilling the stated four objectives and minimizing US and Panamanian casualties. Therefore, in the case of this light-force operation, the proposition holds true that surprise was a necessary combat multiplier that allowed the massing of combat power with minimal enemy response.

Operation Desert Storm

Operation Desert Storm was the US-led coalition reaction to the Iraqi invasion of Kuwait in August of 1990. This offensive occurred in January and February of 1991, after almost six months of air, naval, and ground force buildup. Desert Storm's stated military objectives were (1) attack Iraqi political-military leadership and command and control, (2) gain and maintain air superiority, (3) sever Iraqi supply lines, (4) destroy known nuclear, biological and chemical (NBC) production, storage, and delivery capabilities, (5) destroy Republican Guard forces in the Kuwait Theater of Operations (KTO) and, (6) liberate Kuwait City.²³ This operation provided an example of how surprise can be used in a campaign involving massive numbers of aircraft, troops, and armored

vehicles. The question to be answered, the proposition, and the three units of analysis (the planning and execution of the mission to obtain surprise, the achievement of surprise, and the results) remain the same as the previous two case studies.

Since the gradual buildup of US and coalition forces was apparent to all, the coalition could not hope to achieve strategic surprise against the Iraqis. They could, however, hope to achieve operational surprise (relating to the location of the main effort within theater) and tactical surprise (the date and time of the attack) at the start of both the air campaign and the ground campaign.

To achieve tactical surprise at the start of the air campaign, CENTAF took several steps prior to the attack: desensitizing the Iraqi command structure by flying a high tempo of operations prior to the strikes; masking the launch and movement of mission aircraft; and exploiting situations where repeated tactics created conditioned responses.²⁴ Planners placed special emphasis on desensitization:

The Iraqis were conditioned to the presence of large numbers of AWACS and fighter combat air patrols (CAPs) on the borders with Saudi Arabia and the Persian Gulf. These aircraft flew defensive missions in the same orbits and numbers that would be used for the air offensive. A series of surges began to create a pattern of increased activity one night a week.²⁵

Concurrent with the first wave of the air campaign, the coalition relied on a combination of darkness (the attack was launched just after midnight on January 17th), stealth aircraft (F-117s), Tomahawk land-attack missiles (TLAMs), conventional air-launched cruise missiles (ALCMs) and the destruction of Iraqi early-warning radar sites by attack helicopters to maintain the element of surprise.²⁶

Surprise was also critical for the ground campaign. Since the Iraqi defenses thinned out considerably the further west one traveled from the Kuwait-Saudi border, the CENTCOM plan called for the XVIII and VII Corps to attack as far west as possible to envelope the enemy. The westward shift of these massive forces took place at the last possible minute to prevent detection by the Iraqis.²⁷ To ensure that operational and tactical surprise was maintained for the envelopment, CENTCOM initiated an elaborate deception plan. Prior to and during the air war, the coalition air forces were charged with supporting the ground deception plan by portraying Kuwait as the center of gravity and by shutting down Iraqi reconnaissance collection assets.²⁸ This orchestrated deception operation also included aggressive ground force patrolling, artillery raids, amphibious feints, counterintelligence, and ship movements to focus the Iraqis on Kuwait and disguise the activity taking place 150 miles to the west in the desert.²⁹ The blinding of the Iraqi's intelligence collection capability was especially important since "to attack from the west meant attacking across the desert, and few Iraqi staff officers believed U.S. forces could operate freely across that featureless terrain."³⁰

In both campaigns of Operation Desert Storm, surprise was achieved. For the air campaign, it cannot be argued that some degree of tactical surprise was achieved. Two pieces of evidence to support this statement were the disorganized response of the Iraqi Air Force and the rapid destruction of the Iraqi command and control network and much lauded integrated air defense system.

This was not a gradual rolling back of the Iraqi air defense system. The nearly simultaneous suppression of so many vital centers helped cripple Iraq's air defense system, and began seriously to disrupt the LOCs between Saddam Hussein and his forces in the KTO and southeastern Iraq.³¹

This total destruction of the Iraqi air defense system would not have been possible without the tactical surprise provided by stealth aircraft, cruise missiles, and low-flying attack helicopters.

In the ground campaign, the achievement of operational and tactical surprise was total. The 150 mile westward swing by two entire corps over a three week period, "one of the largest and longest movements of combat forces in history," went totally undetected by the Iraqis.³² Once the attack began, the Iraqis were shocked with the size and speed of the coalition force on their western flank. In one account of a captured Iraqi battalion commander:

Expressing surprise that Americans were in front of his forces, he lacked specific Coalition force dispositions: this illustrates Iraq's weak battlefield intelligence capabilities, the breakdown of communications with higher headquarters, and the success of the Coalition in achieving surprise.³³

The massive heliborne operation by the 101st Airborne Division (Air Assault) in the XVIII Corps zone met with only "scattered and disorganized" Iraqis.³⁴

The early results of Desert Storm were also impressive. Five minutes after the start of the air campaign, nearly twenty air defense, electrical, leadership, and command, control and communications nodes had been struck in Baghdad; within an hour another twenty-five similar nodes had been struck; by the end of the first day, nearly four dozen targets had been hit. By the eve of the ground campaign, nearly 100,000 combat and support sorties and over 300 cruise missile launches had

succeeded in achieving air supremacy, decimating the world's sixth largest air force, isolating Iraq's leadership, and reducing the combat effectiveness of Iraqi forces in the KTO by 50 percent and in the rear echelons by 25 percent. After the kick-off of the ground campaign, the coalition air forces continued the destruction of Iraqi strategic targets, such as chemical weapons production facilities, and provided interdiction and close air support for the ground forces. This incredible success was accomplished at a cost of 41 coalition aircraft lost during the entire war.³⁵

The results of the offensive ground campaign mirrored that of the air campaign. The lightning ground offensive by the units of the relocated XVIII and VII Corps in the west quickly overwhelmed the enemy. By the end of the first day, "the Iraqi forward corps were assessed as combat ineffective. . . . Iraqi corps commanders could not see the battlefield and did not understand the scope and intent of Coalition ground forces operations".³⁶ The 100-hour ground offensive achieved its goals by ejecting Iraqi forces from Kuwait and cutting off and destroying Republican Guards Forces. During operation Desert Storm, an estimated 3,847 tanks, 2,917 artillery pieces, and 1,450 armored personnel carriers were destroyed or captured. Approximately 86,000 Iraqi prisoners were taken. These phenomenal accomplishments came at a cost of relatively few coalition casualties, considering the size of the force engaged.³⁷

As with the first two case studies, the units of analysis for Desert Storm lead to some direct matches between the factual data and the proposition. Using desensitization of the Iraqi commanders, stealth

and cruise missile technology, and the cover of darkness, the coalition air forces planned and executed the element of tactical surprise. Using an elaborate deception plan and the secretive intra-theater deployment of ground forces coupled with the destruction of Iraqi intelligence collection assets, surprise at the operational and tactical levels was planned for and executed by the US-led coalition forces. Surprise was achieved as demonstrated by the rapid destruction of the Iraqi command and control structure and integrated air defense system by the coalition air campaign and by the overwhelming success of the western envelopment by the ground forces. This achievement of operational and tactical surprise was a critical component of the overall success of Operation Desert Storm and assisted in the fulfillment of stated objectives. Surprise also contributed to the relatively small number of casualties on the coalition side. Therefore, in the case of this large air and ground operation, the proposition holds true that surprise was a critical combat multiplier that allowed the massing of combat power with minimal enemy response.

The intent of these case studies has been to establish a baseline on the use of surprise by US military forces. By using Yin's methodology, the proposition has been defended using a logical sequence of evidence. The next section will analyze the capabilities of remote sensing systems, with respect to pertinent military observables present during these case studies.

Measurement Research

In this section, measurement research, as defined by Simon and Burstein, is used to systematically determine if several programmed and proposed commercial satellite imaging systems have the capability to collect information relevant to the defeat of military surprise. Specifically, the analysis focuses on three criterion (quality, timeliness, and accessibility) to determine if these systems are useful to a foreign military for Indications and Warning (I&W) and Combat Intelligence tasks. These criterion are used to answer the question: What are the current capabilities and trends in civilian satellite imaging systems and what operational utility do they have? The approach is to determine the key parameters (and their thresholds) of the programmed and proposed systems that impact the criteria in the context of the surprise-defeating missions of I&W and Combat Intelligence. The analysis determines which systems have operational military utility for these missions.

Key System Parameters

Based on the satellite information in Chapters 1 and 2, five programmed and proposed satellite imaging systems, available within the next five years, were chosen for further analysis: LANDSAT 7, SPOT 5, EYEGLOSS, CRSS, and WORLDVIEW. Their system capabilities are shown in Table 3. The next step determines which of these parameters has an impact on quality, timeliness, and accessibility, with respect to the missions of I&W and Combat Intelligence.

TABLE 3
SUMMARY OF KEY SATELLITE PARAMETERS

SYSTEM	LANDSAT 7	SPOT 5	EYEGLOSS	CRSS	WORLDVIEW
PAN RES.	15-METER	5-METER	1-METER	1-METER	3-METER
SCENE SIZE	LARGE	LARGE	MEDIUM	MEDIUM	MEDIUM
MSI?	YES	YES	NO	YES	YES
ALTITUDE	705 KM	800 KM	700 KM	680 KM	476 KM
REVISIT	16 DAYS	3-26 DAYS	2 DAYS	3 DAYS	2.5 DAYS
DATE	1998	1999	EARLY 1997	1997	LATE 1995
OWNERSHIP	US	FRANCE	US	US	US
OVERSEAS GND STN.?	YES	YES	YES	NO	YES

Quality

From the discussion in Chapter 1 on Remote Sensing Terminology, the four critical parameters used to characterize the quality of remotely sensed digital imagery data are spatial resolution, spectral resolution, area coverage, and revisit time. The first three parameters correlate directly to the panchromatic resolution, the availability of multispectral imagery (MSI) bands, and the scene size, respectively. Revisit time is analyzed as the key attribute under the timeliness section.

The importance of spatial resolution for the two missions of I&W and Combat Intelligence is readily apparent. As stated in Chapter 2, Indications and Warning focuses on the monitoring of such

operational-level fixed locations as choke points, crossroads, garrisons, airfields, and naval ports to provide forewarning of enemy actions or the imminence of hostilities. To perform this mission, a remote sensing system must be of a high enough spatial resolution to allow the detection of individual armored vehicles, mobile artillery and missiles, attack and transport aircraft, and surface ships. Two potential examples of Indications and Warning can be drawn from the El Dorado Canyon and Just Cause case studies. The first example would have been the Libyan detection of abnormally high numbers of F-111s or tankers at RAF Lakenheath or RAF Mildenhall. The second example would have been the Panamanian detection of large numbers of transport aircraft at Pope AFB (near Fort Bragg) or various other US airfields or the accumulation of armored vehicles and helicopters in Panama.

Combat Intelligence focuses on searching the battlefield for concentrations of enemy formations and for indirect activity indicators. For this mission, the spatial resolution must be adequate enough to detect many of the same items as listed for I&W, but also should be able to detect mobile command and control headquarters, unit assembly areas, logistics areas, and scarring of the earth and snow due to the movement of vehicles. From the Desert Storm case study, one potential example of Combat Intelligence would have been the Iraqi detection of vehicles and assembly/logistics areas of the two coalition corps that shifted 150 miles west across the desert.

Table 4 shows the approximate minimum spatial resolutions needed for detection of each of the target observables listed above. Some of the resolutions are interpolated from source information. From

Table 4, it can be seen that high spatial resolution is a critical attribute for any system hoping to collect against the two missions.

TABLE 4
DETECTION OF TARGET OBSERVABLES

TARGET OBSERVABLES	SPATIAL RESOLUTION (METERS)
ARMORED VEHICLES	1
MOBILE ARTILLERY AND MISSILES	1
MOBILE COMMAND & CONTROL HQs	3
ATTACK AND TRANSPORT AIRCRAFT	4.5
ASSEMBLY AREAS	6
LOGISTICS AREAS	5-10
GROUND AND SNOW SCARRING	5-10
SURFACE SHIPS	7.5-15

Source: Implications for Nations Without Space-Based Intelligence - Collection Capabilities by Jeffrey T. Richelson³⁸

The importance of improved spectral resolution (more discrete spectral bands) on the I&W and Combat Intelligence missions, and hence the observables shown in Table 4, is provided by the ability of multispectral imagery to detect camouflage material and surface disturbances on the earth and snow. These two phenomena may be detected easier using a multispectral system with lower spatial resolution than with a panchromatic system with higher spatial resolution. If camouflage is used to conceal vehicles and aircraft in garrison or in assembly areas or if large numbers of tracked vehicles tear up the

ground or snow (as in the Desert Storm case study), multiple spectral bands can be useful. Therefore, the presence of a multispectral capability in a commercial imaging system can be viewed as being value added.

The importance of area coverage for the two missions of interest varies. For the Indications and Warning mission, since the focus is on fixed areas such as garrisons and airfields, probably encompassing areas less than ten-by-ten square kilometers (as in the El Dorado Canyon and Just Cause case studies), a system with a smaller synoptic imaging area is sufficient. For the Combat Intelligence mission, since the focus is on a larger area potentially encompassing an entire theater (as in the Desert Storm case study), a system with a larger synoptic area is required.

Timeliness

The criteria of timeliness correlates directly to the revisit time shown in Table 3. For both of the required missions, "the ability of a satellite to cover a large number of geographically dispersed targets in a short period of time and to revisit targets relatively frequently is . . . of particular value in providing definitive assurance that no hostile action is imminent."³⁹

The probability of a satellite imaging system detecting a given observable is dependent on the transience of the observable and the orbital and imaging characteristics of the satellite system. Highly transient observable examples include the strike and transport aircraft during Operations El Dorado Canyon and Just Cause, which were present at

their respective airfields for less than a day. Less transient observable examples include the in-country force buildups and deployments in Operations Just Cause and Desert Storm, which were present from days to weeks before the surprise attack. Obviously, for both the I&W and Combat Intelligence missions the preferred solution is to have a satellite imaging system which can provide continuous coverage. Since continuous coverage is not feasible with the programmed and proposed commercial satellite imaging systems, the next best solution is to maximize revisit to try to increase the probability of detecting transient targets.

Accessibility

Accessibility is more difficult than the others to quantify. Two of the key parameters shown in Table 3, country of ownership and the presence of overseas ground stations and licensing agreements, play a critical role in determining accessibility. Since the issue of countermeasures, such as policy and diplomacy, is not discussed until later in this chapter, an estimate of accessibility must be made using these two parameters alone. Within this guideline, it is intuitive to state that if a system is owned by a foreign country, has ground stations within a foreign country, or has licensing agreements with foreign countries, access to the imagery will be easier for a potential adversary than if the opposite is true.

Criterion Threshold and System Selection

A summary of the analysis of the key system parameters from the previous section yields the results shown in Table 5. For the relative

importance of each of the parameters, a scale of 3 (most important) to 1 (least important) was used. The assessment of relative importance and the minimum thresholds shown in Table 5 were validated based on an interview with James M. Fry, a senior scientist with the National Photographic Interpretation Center (NPIC). Mr. Fry's 31 years of experience in the fields of satellite imagery science and exploitation qualifies him to make these subjective determinations based on his knowledge of the missions and observables.⁴⁰

For example, in the case of spatial resolution, the most stringent observables (detection of armored vehicles and mobile artillery/missiles) require a spatial resolution of one meter. The least stringent observable (detection of surface ships) requires a spatial resolution of between 7.5 and 15 meters. Mr. Fry concurred that the threshold of three meters is the minimum level needed to perform the I&W and Combat Intelligence tasks with a high level of confidence.

A decision matrix (shown in Table 6) can now be created to select those programmed and proposed imaging systems which are most applicable for use by a potential adversary for performing I&W and Combat Intelligence missions against US forces. The left column depicts the five systems under consideration. The other columns show the critical parameters related to the criteria. The number in parentheses under each of the parameter headings is the relative importance rank from Table 5, now used as the weighting factor. Under each of these columns are two numbers for each of the systems. The first number is the parametric rank assigned to that system. The guidelines used in the

TABLE 5
CRITERIA RANKS AND THRESHOLDS

CRITERIA/PARAMETER	RELATIVE IMPORTANCE RANK	MINIMUM THRESHOLD
QUALITY		
SPATIAL RES.	3	Less than 3-METERS
SPECTRAL RES.	1	MSI CAPABILITY
AREA COVERAGE	2	Greater than 10X10 KM
TIMELINESS		
REVISIT TIME	3	Less than 3 DAYS
ACCESSIBILITY		
OWNERSHIP	2	FOREIGN
O/S GND. STN.	2	YES

assignment of these parametric ranks are as follows: (1) a scale from one to five was used; (2) if the system does not meet the minimum threshold for that parameter as shown in Table 5, it is given a rank of one (worst); (3) the best system(s), relative to the others, exceeding the threshold, is given a rank of five (best); and (4) the systems which meet the threshold, but to lesser degree than the best system, are given a rank between two and four (moderate).

The second number in each column is the product of the weighting factor multiplied by the parametric rank. This results in a weighted parametric rank. These weighted parametric ranks are then summed across each row (for each system) and shown in the far right column. In this case, the system with the largest number is best for use against the mission areas of I&W and Combat Intelligence.

TABLE 6

WEIGHTED DECISION MATRIX

PARAMETERS SYSTEMS	SPATIAL RES. (3)	SPECTRAL RES. (1)	AREA COV. (2)	REVISIT TIME (3)	OWNER- SHIP (2)	O/S GROUND STATION (2)	TOTAL RANK (WGTD)
EYEGLOSS	5 (15)	1 (1)	4 (8)	5 (15)	1 (2)	5 (10)	51
WORLDVIEW	4 (12)	4 (4)	4 (8)	4 (12)	1 (2)	5 (10)	48
SPOT 5	1 (3)	4 (4)	5 (10)	3 (9)	5 (10)	5 (10)	46
CRSS	5 (15)	4 (4)	4 (8)	4 (12)	1 (2)	1 (2)	43
LANDSAT 7	1 (3)	5 (5)	5 (10)	1 (3)	1 (2)	5 (10)	33

Therefore, the best three commercial satellite imaging systems are EYEGLOSS, WORLDVIEW, and SPOT 5.

Relationship Research

During this phase, two causal relationships will be analyzed. The first speculates as to the effect of the remote sensing systems from the measurement research section on the element of surprise from the case studies. The second is an examination of the potential for various countermeasures to counteract the threat to surprise.

Systems versus Surprise

Given the analysis completed in the previous two sections, the following question can now be answered: Independent of countermeasures, will the proliferation of remote sensing systems impact surprise? From the baseline established by the three case studies, a new speculative

look at the potential to defeat surprise can now be taken using the selected imaging systems. In other words, if imagery data from the three systems selected from Table 6 were available to the Libyans, Panamanians, and Iraqis in a timely manner, would it have allowed them to anticipate the surprise attacks and counteract the massing of overwhelming combat power?

For this speculation, since the assumption is that they would have access to the data, quality and timeliness are the only applicable criteria. A revised summary of the selected satellite systems is shown in Table 7.

TABLE 7.

SELECTED SATELLITE SYSTEMS AND PARAMETERS

SYSTEM PARAMETER	SPOT 5	EYEGLOSS	WORLDVIEW
PAN RES.	5-METER	1-METER	3-METER
SCENE SIZE	LARGE	MEDIUM	MEDIUM
MSI?	YES	NO	YES
ALTITUDE	800 KM	700 KM	476 KM
REVISIT	3-26 DAYS	2 DAYS	2.5 DAYS
DATE	1999	EARLY 1997	LATE 1995

For El Dorado Canyon, the air-only example, the ability of any of these systems to detect the observables necessary to forewarn of the strike seems probable. The spatial resolution of these systems (from one-to-five meters) would have been adequate to detect the F-111 and

tanker aircraft. The area coverage of all of the systems would have been sufficient to monitor a target the size of an airfield. However, as relayed by Major Hodgdon, the number of aircraft at the air bases in England was not unusual for the ongoing exercise. To be able to truly determine the intentions of the US, an imaging system would have required a revisit time greater than that of the selected systems. This capability would have allowed the closer monitoring of these facilities to determine activities not compatible with normal procedures.

For Operation Just Cause, the light-force example, several of the same points apply. In addition to being able to detect the transport aircraft at CONUS airfields, one of the systems, EYEGLASS, would have been able to detect the armored vehicles and helicopters being brought into Panama. Also, since the target areas were all fixed facilities, area coverage would not have been a challenge. However, the revisit times available to these systems could not guarantee a high probability of catching these observables during the limited time that they were available for viewing. Also, since most operations were conducted at night, the lack of thermal imaging bands (with adequate spatial resolution) would preclude their use for other than daylight operations in a sun-synchronous mode.

Desert Storm provides an example where these systems could have provided excellent support. For this large air and ground campaign, the spatial resolution of all five systems would have been sufficient to detect the movement of the enormous numbers of armored vehicles and helicopters to the west, with their associated ground scarring, and the formation of massive assembly and logistics areas. The area coverage of

all the systems would have been sufficient, since the buildup took several weeks and a search strategy of collecting overlapping images could have been used to create a large area mosaic. For this very reason, timeliness of collection would not have been a driving parameter; all of the systems could have performed adequately.

Countermeasures versus Systems

The second causal relationship addresses the issue of how countermeasures could have prevented these systems from defeating surprise. The relevant secondary question is as follows: Given the proliferation of unclassified satellite imaging systems with military utility, what can the US do from policy and countermeasure perspectives to reduce the effect of these systems on surprise during military operations? The two areas analyzed are policy and diplomatic issues and active and passive countermeasures.

Policy and Diplomacy

As mentioned in Chapter One, the Presidential Decision Directive signed on 9 March 1994 outlines a US policy to prevent the release of data from US-controlled satellite systems to adversaries in time of crisis. For systems that are US-owned and have no foreign ground stations or licensing agreements, this policy should be sufficient to prevent access. However, as is the case with the selected systems, foreign control or partnership complicates the situation and leads to the need for diplomacy.

In the Desert Storm case study, diplomatic means were used successfully to prevent the release of French-controlled SPOT imagery data to the Iraqis. As stated in the Gulf War Air Power Survey:

A problem for Saddam and his commanders was the lack of detailed information about coalition intentions and capabilities necessary for detailed planning. Although Iraq had archival SPOT satellite imagery, it was probably unable to acquire much current imagery due to sanctions. . . . Coalition members cooperated to deny Iraq access to commercial satellite imagery products by halting the flow of SPOT images from France.⁴¹

It can therefore be assumed, with some level of confidence, that in future combined operations coalition allies will probably cooperate in the denial of access to imagery by a common enemy.

Passive and Active Countermeasures

Passive means include such doctrinal or procedural activities as restricting operations to times when the satellite will not be overhead, or when it cannot image effectively (e.g., during nighttime or under heavy clouds for electro-optic systems), and using cover, concealment, and deception practices (CC&D). In all three case studies, these passive means were used extensively. In both El Dorado Canyon and Just Cause, night operations were the cornerstone of operational security. Also, in Just Cause the use of concealment played a major role. In all three operations, extensive deception plans and desensitization of the opponent contributed to the maintenance of surprise.

These techniques worked against enemies that did not have access to space, but what if data from the selected systems had been available to these adversaries? For Operations El Dorado Canyon and

Just Cause, the emphasis on night operations and concealment would have been sufficient to thwart any of the three systems in Table 7. For Desert Storm, desensitization and night operations would have been successful in maintaining surprise for the initiation of the air campaign. However, for the ground campaign, no amount of passive countermeasures could have prevented the Iraqis from detecting the main effort to the west.

Active Countermeasures

Active countermeasures are a much more serious undertaking. They use kinetic-energy or directed-energy weapons to destroy or to damage the orbiting satellite imaging system. Kinetic-energy weapons use hard-kill techniques to destroy the satellite. Disadvantages include a relatively low-orbit capability and the lack of plausible deniability. Directed-energy weapons use lasers or high-power microwaves to either hard-kill, soft-kill (non-destructive), or to degrade the satellite. Advantages over kinetic-energy weapons include higher-orbit capability and plausible deniability. Plausible deniability would be an advantage when it becomes necessary to destroy a satellite owned by a friendly country which refuses to deny data access to an adversary.⁴²

For the selected systems, all will be placed in orbits higher than can normally be reached by current kinetic energy weapons. However, estimates of the range of potential directed energy weapons are from 400-to-1200 kilometers for lasers and 500 kilometers for high-power

microwaves.⁴³ These systems would have the ability to destroy or disrupt these imaging systems.

Summary

This chapter has included analysis to answer the secondary and primary questions of the thesis. By using case study methodology, measurement research, and relationship research, a factual baseline for surprise has been established and a quantitative assessment of commercial satellite imaging systems has been completed. Additionally, the relationship among surprise, certain future systems, and countermeasures was examined and correlated. The next chapter summarizes the answers to the research questions and offers recommendations for further study.

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CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This final chapter summarizes the findings to the primary and secondary thesis questions. It also makes recommendations for further inquiry.

Thesis Questions

During the course of analysis in the previous chapter, the answers to the secondary questions were discovered. This section compiles them and forms an answer to the primary thesis question.

Secondary Question 1

What are the current capabilities and trends in civilian satellite imaging systems and what operational military utility do they have?

The measurement research analysis showed the current trend is toward increased capability. Systems on the order of one-to-three-meter spatial resolution, with multispectral bands, moderate area coverage, and two-to three-day revisit times will be available to commercial customers within the next few years. These systems will detect a broad range of observables related to the critical missions of Indications and Warning and Combat Intelligence.

Secondary Question 2

What is the element of surprise and how does it support achievement of operational and tactical military objectives?

Doctrinal references combined with case study methodology clearly demonstrates that surprise is a high-pay off element of warfare. Surprise acts as a force multiplier by allowing the massing of overwhelming combat power versus the enemy's weakness while, at the same time, not allowing the enemy time to react effectively. Analysis of Operations El Dorado Canyon, Just Cause, and Desert Storm showed that surprise which is planned for, executed, and achieved at the operational and tactical levels of warfare is critical for the achievement of military objectives with minimal casualties.

Secondary Question 3

Independent of countermeasures, will the proliferation of remote sensing systems impact surprise?

Using causal relationship research in Chapter Four, an analysis of the effect of the top three selected imaging systems versus the element of surprise was completed. For the two cases which relied on air-only strikes and light force deployments--El Dorado Canyon and Just Cause, respectively--the temporal nature of the aircraft, concealment, and night operations made it very difficult for commercial imaging systems to defeat the element of surprise. For the case involving the buildup of a large air and ground force (Desert Storm), the selected systems would have had a relatively easy time detecting the key observables and therefore defeating the element of surprise.

Secondary Question 4

Given this proliferation, what can the US do from policy and countermeasure perspectives to reduce the effect of these systems on surprise during military operations?

The research showed that the most effective methods of countermeasure were night operations, extensive deception and desensitization plans, concealment, and the use of diplomatic means to prevent the passing of satellite imagery data from friendly countries to adversaries.

Primary Thesis Question

Can the United States achieve military surprise at the operational and tactical levels of war with the continuing proliferation of unclassified satellite imaging systems?

In most cases the answer is yes. As shown by the answers to the secondary questions, in most operations the US can defeat the systems that are programmed and planned for the next five years using unilateral methods. According to the US Army Training and Doctrine Command, "most of the conflicts involving the U.S. Army will be OOTW [operations other than war] or low-intensity conflicts, as few states will risk open war with the U.S."¹ Surprise can therefore be achieved for the majority of the types of operations that the US is likely to be involved in (e.g., air-only strikes and light force deployments). In the event of a large-scale buildup of air forces and ground forces (previously delivered by air and sea lift) in a foreign country, the maintenance of operational and tactical

surprise is very unlikely, primarily due to the capabilities and nature of control of the upcoming commercial satellite imaging systems.

Recommendation for Further Inquiry

From the analysis, one major area for further inquiry becomes apparent: the effect of different sensors on surprise. The focus of this thesis has been the commercial imaging systems that will be available within the next five years. It so happens that these systems are primarily electro-optic systems that rely on reflected solar energy from the earth's surface. As mentioned in Chapter 1, two other types of sensors are those that detect emitted energy (e.g., thermal) and active sensors (e.g., radar). These sensors, which operate effectively day or night, would negate the night time sanctuary that forces currently rely upon. Commercial imaging satellites that included these types of sensors, at a spatial resolution that could detect observables of military interest, would pose a major challenge to the achievement of the element of surprise. These systems can defeat one of the major techniques used in the case studies to overcome detection: night operations.

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